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Effect of Chromium on Phase Formation of Intermetallic Aluminum Alloys in the Al-Fe-Si System

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ABSTRACT
The article explores the prospects for the development of Kazakhstan's aluminum industry, with a focus on the application of additive manufacturing technologies for the synthesis of chromium-alloyed composite aluminum alloys in the Al-Fe-Si system. A comprehensive metallographic and thermodynamic analysis of the phase composition of alloys synthesized by consumable electrode surfacing was carried out. The use of Thermo-Calc software enabled the construction of polythermal sections and the assessment of the influence of alloying element concentrations on the formation of intermetallic phases, including $Al_{13}Fe_4$ (θ-phase) and Al_8Fe_2Si. The optimal chromium alloying conditions were substantiated, ensuring reduced brittleness and improved mechanical properties through the formation of a fine-grained structure, stabilization of the phase composition, and removal of large primary dendrites. The obtained results confirm the potential of chromium alloying as an effective approach in developing intermetallic aluminum alloys with the desired properties. The study's results contribute to the advancement of technologies for producing aluminum alloys with enhanced performance characteristics, thereby expanding the potential for industrial applications of additive manufacturing methods.

Keywords: AlFeSi, intermetallic phases, simulation and modelling, diagrams phase transformation, microstructure.

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Introduction

Currently, the prospects for the development of the aluminum industry in the Republic of Kazakhstan appear highly promising, driven by a number of key factors. First, the modernization of production facilities is actively ongoing, which undoubtedly contributes to increased technological efficiency, reduced energy consumption, and enhanced competitiveness of domestic products on the international market.

Second, the implementation of innovative technologies, including additive manufacturing methods for synthesizing composite materials, opens up new opportunities for the creation of high-performance aluminum alloys with improved operational characteristics [1].

In addition, government support and the attraction of investments into the sector create favorable conditions for expanding production capacities and entering new markets. Collectively, these factors ensure the sustainable development of Kazakhstan's aluminum industry, strengthening its position both regionally and globally.

Modern processing technologies for metallic materials have a significant impact on improving their properties [[2], [3], [4], [5], [6], [7], [8], [9]]. At the same time, layer-by-layer material deposition (additive manufacturing) offers a unique opportunity for precise and fine-tuned control over the structure and composition of alloys [[10], [11], [12], [13], [14]]. Unlike conventional casting and machining methods, additive techniques allow the production of complex composite materials with tailored properties, enhancing the strength, ductility, corrosion resistance, and electrical conductivity of aluminum alloys [[15], [16]].

Particularly promising is the alloying and microalloying of aluminum alloys with various elements to achieve the desired levels of mechanical and service properties [[17], [18], [19], [20], [21]]. Similar improvements can also be achieved by altering the equilibrium conditions of phase transformations in alloys. Of growing interest is the Al–Fe–Si–X system, where intermetallics are used as strengthening phases.

For example, in [22], the authors investigated the influence of cooling rate and subsequent hot strengthening on the microstructure and mechanical properties of an Al–20Si–5Fe–2X alloy (X = Cu, Ni, and Cr). The samples were produced via gas atomization with cooling rates of 1×10^5 K/s and 5×10^7 K/s. The results showed a significant effect of cooling rate and the presence of transition metals on the microstructure and mechanical strength of Al–20Si–5Fe alloys. The beneficial effect of transition metals on the thermal stability of Al–20Si–5Fe, particularly for Ni-containing alloys, was noted.

In studies of the Al–Fe–Si system, iron is generally considered to have a detrimental effect on Al–Si alloys, as it promotes the formation of needle-like intermetallic phases, which considerably reduce the operational properties of the final product. The adverse effects of iron are mitigated through alloying with elements such as chromium, manganese, and rare earth metals. On the other hand, [23] proposed using Fe to counteract the negative influence of Si. The authors studied the effect of Fe content and subsequent homogenization on a dilute Al–Si alloy. An increase in electrical conductivity was observed with the specific addition of Fe. Moreover, the tensile strength and electrical conductivity of the Al–Fe–Si alloy could be further improved after homogenization. It was suggested that the favorable performance characteristics of the Al–Fe–Si alloy may be attributed to the formation and evolution of the ternary eutectic phase α-Al_8Fe_2Si. It was also found that elevated homogenization temperatures and grain refinement promote the precipitation of the α-phase.

In [24], rapidly solidified Al–20Si–5Fe–2X alloys (X = Cr, Zr, or Ni), produced via gas atomization, were degassed under varying vacuum conditions before hot extrusion. The study demonstrated that the addition of a fourth element leads to the formation of dispersed particles that contribute to improved mechanical properties, particularly at elevated temperatures.

It is well known that the addition of alloying elements such as manganese and chromium suppresses the formation of the θ-phase ($Al_{13}Fe_4$) in favor of the less detrimental α-Al_{15}(Fe, Mn, Cr)$_4Si_2$ phase, which is less brittle and less prone to cracking. Silicon is added to promote the precipitation of the Al_8Fe_2Si phase in the alloy [[25], [26]].

The objective of this study was a fundamental investigation of the Al–Fe–Si system. The work focused on identifying optimal concentrations and temperatures for the formation of the high-symmetry Al_8Fe_2Si phase when chromium is used as an alloying element.

Experimental part

An Al-Fe-Si system alloy of the base modification (a system in which impurity atoms are present as a result of processing the original charge components) was produced using additive technology through synthesis by surfacing with a horizontally oriented consumable electrode. Commercial-grade materials were used as the charge. The electrode was made of St3-grade steel, with dimensions of 2×20×150 mm. Aluminum was introduced into the alloy by melting aluminum sheets of AD31 grade, sized 2×30×100 mm. Silicon was introduced using KR00-grade silicon, crushed to a -63 µm fraction.

Before synthesis, a layered package was prepared from aluminum and silicon, consisting of four aluminum sheets with silicon applied between the layers using a wet method. After application, the package was assembled and dried at room temperature for no less than 24 hours. The package was then placed on a steel substrate made of St3-grade steel, which did not participate in the synthesis process. The top of the package was covered with a pumice-like flux of AN-348 grade to prevent additional alloying of the melt with flux components. The target composition of the alloy was Al–30Fe–10Si (at.%).

After synthesis, semi-elliptical ingots were obtained, which were then sectioned into templates for metallographic analysis. Microsections were prepared using standard techniques, including coolant-assisted cutting, grinding, and polishing with lubricants. Metallographic investigations were carried out using an Altami optical microscope. The resulting microstructure is shown in Figure 1.

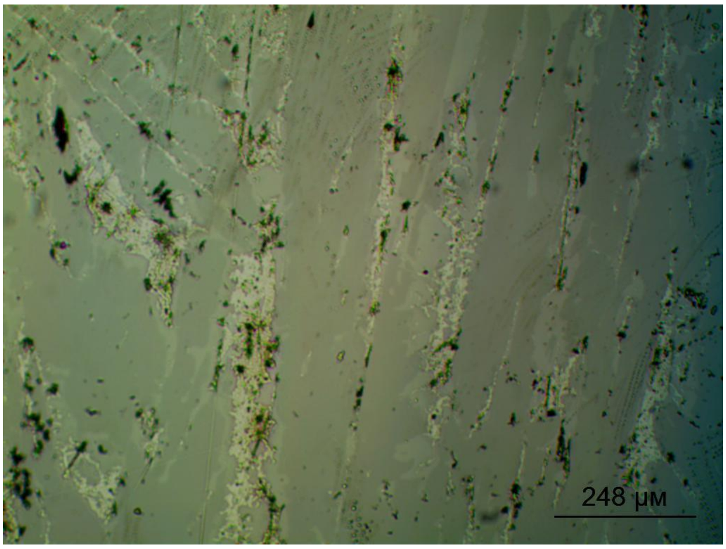

Figure 1 - Microstructure of the Al-Fe-Si alloy of the basic modification after synthesis, x200

As seen, the microstructure exhibits a distinct directional pattern of structural constituents. It is composed of alternating intermetallic dendrites and aluminum layers with minimal dissolution of both base and alloying components. This type of morphology tends to degrade mechanical performance, particularly ductility. As demonstrated in [27], one effective way to mitigate this issue is alloying, including microalloying, with elements that promote dissolution of the primary binary θ-phase during alloy cooling.

Considering the composition under study, the θ-phase is expected to be present at room temperature, but conditions must be created for the formation of a secondary θ-phase – i.e., one that precipitates as a result of solid-solid phase interactions. Accordingly, this study explores the potential of alloying the base-modified Al-Fe-Si alloy with chromium and investigates the fundamental aspects of such alloying.

Results and Discussion

For a more substantiated selection of alloying element concentrations and optimization of heat treatment regimes, a comprehensive analysis focusing on the phase composition of the alloy is required. The analysis was performed excluding impurities and trace elements introduced during synthesis, in order to concentrate solely on the influence of chromium additions. This analysis was conducted using Thermo-Calc software, version 2024a, with the aluminum-based thermodynamic database TCAL8.2.

Thermo-Calc is a computational tool for the calculation of phase equilibria, based on the global minimization of the Gibbs free energy in multicomponent systems. The software also enables the calculation of thermodynamic properties of phases (such as Gibbs energy, enthalpy, and others), including metastable equilibria. A key feature of Thermo-Calc is its modular and extensible architecture, along with a continually expanding database of elements for various systems, including metallic, salt, oxide, and aqueous solution systems.

The program allows for the calculation of phase diagrams of multicomponent systems, including the construction of polythermal and isothermal sections, phase composition predictions, and cooling curve simulations – all of which were employed in this study.

Using Thermo-Calc (version TCW8 with database TCAL8.2), Al-based systems were analyzed to determine the concentration boundaries for the formation of primary crystals of Fe-containing phases.

Figure 2 shows a polythermal section of the Al–30Fe–9Si–1Cr system with variable aluminum and iron content. Chromium alloying was introduced by reducing the aluminum fraction.

According to Table 1, under equilibrium conditions, aluminum and iron form solid solutions, intermetallic compounds, and eutectic mixtures. As shown in the section diagram, during solidification of an aluminum–iron alloy, the $Al_{13}Fe_4$ phase (~59.41 at.% Al) appears in the structure, forming via a peritectic reaction at 997 °C. At approximately 18 at.% Fe and a temperature of 622 °C, a eutectic transformation occurs, resulting in the formation of an aluminum solid solution (Al).

Further increases in iron content in the alloy lead to the formation of the following chemical compounds: $Al_{15}Si_2Cr_4$ (~61.43 at.% Al), AlFeSi (~51.44 at.% Al), Al_8Fe_2Si (~58.17 at.% Al), and $Al_9Fe_2Si_2$ (~60.1 at.% Al).

Table 1 - Distribution of phase regions depending on temperature

Designation	Phase domain
1	Liquid
2	Liquid + $Al_{13}Fe_4$
3	Liquid + $Al_{13}Fe_4$+ $Al_{15}Si_2Cr_4$
4	Liquid + $Al_{13}Fe_4$+ $Al_{15}Si_2Cr_4$+ AlFeSi
5	Liquid + $Al_{15}Si_2Cr_4$
6	Liquid + $Al_{13}Fe_4$+ $Al_{15}Si_2Cr_4$ + Al_8Fe_2Si
7	Liquid + $Al_{15}Si_2Cr_4$+ Al_8Fe_2Si
8	Liquid + $Al_{15}Si_2Cr_4$+ Al_8Fe_2Si + $Al_9Fe_2Si_2$
9	$Al_{15}Si_2Cr_4$+ Al_8Fe_2Si + $Al_9Fe_2Si_2$+ (Al)
10	$Al_{15}Si_2Cr_4$+ Al_8Fe_2Si + $Al_9Fe_2Si_2$
11	$Al_{15}Si_2Cr_4$+ Al_8Fe_2Si
12	$Al_{13}Fe_4$+ $Al_{15}Si_2Cr_4$+ Al_8Fe_2Si
13	$Al_{13}Fe_4$+ $Al_{15}Si_2Cr_4$+ Al_8Fe_2Si + AlFeSi
14	$Al_{13}Fe_4$+ $Al_{15}Si_2Cr_4$+ AlFeSi

The $Al_{13}Fe_4$ phase, also known as the θ-phase, is one of the most structurally complex intermetallic compounds, possessing a monoclinic unit cell. It is important to note that the formation of this phase in the form of needle-like particles or large, highly oriented intermetallic dendrites significantly reduces the technological ductility of aluminum alloys. The θ-phase ($Al_{13}Fe_4$) can have a detrimental effect on the mechanical properties of the alloy due to its inherently low ductility and impact toughness.

When this phase forms as large inclusions, it may act as a crack initiation site under mechanical loading and also degrades the overall quality of the cast metal structure. Therefore, the presence of this phase requires particular attention, especially in the development of alloys produced using additive manufacturing technologies.

Table 2 presents the calculated parameters of primary crystallization for the Fe-containing phase in the Al–30Fe–9Si–1Cr system.

Table 2 - Calculated parameters of primary crystallization of the Fe-containing phase in the Al–30Fe–9Si–1Cr alloy system

Phase	Content of components, %			
	Al	***Fe***	***Si***	***Cr***
t = 1083 °C (1 area)				
Liquid	73.58	16.41	9.00	1.00
t = 997 °C (2 area)				
Liquid	59.61	28.07	11.06	12.49
$Al_{13}Fe_4$	59.41	39.85	0.72	0.00
t = 878 °C (3 area)				
Liquid	73.08	15.9	10.8	0.21
$Al_{13}Fe_4$	59.55	39.49	0.95	0.00
$Al_{15}Si_2Cr_4$	63.18	21.79	08.05	06.96
t = 820 °C (4 area)				
Liquid	73.00	13.84	13.12	0.03
$Al_{13}Fe_4$	59.22	39.37	14.03	0.00
$Al_{15}Si_2Cr_4$	61.92	23.91	8.13	6.02
AlFeSi	51.21	33.9	14.88	0.00
t = 799 °C (5 area)				
Liquid	84.16	9.18	6.51	0.14
$Al_{15}Si_2Cr_4$	63.05	20.27	9.5	7.16
t = 742 °C (6 area)				
Liquid	83.03	9.52	7.44	0.0004
$Al_{13}Fe_4$	59.54	39.23	12.2	0.00
$Al_{15}Si_2Cr_4$	61.75	25.64	8.22	4.38
Al_8Fe_2Si	56.91	32.54	10.54	0.00
t = 686 °C (7 area)				
Liquid	86.98	4.36	8.65	0.000
$Al_{15}Si_2Cr_4$	61.25	26.27	8.69	3.77
Al_8Fe_2Si	57.38	32.55	10.05	0.00
t = 622 °C (8 area)				
Liquid	89.76	2.09	8.13	0.000
$Al_{15}Si_2Cr_4$	60.56	27.03	9.35	3.04
Al_8Fe_2Si	57.94	32.56	9.49	0.00
$Al_9Fe_2Si_2$	58.03	26.9	15.06	0.00
t = 569 °C (9 area)				
$Al_{15}Si_2Cr_4$	61.00	26.63	8.93	3.42
Al_8Fe_2Si	59.67	32.58	7.74	0.00
$Al_9Fe_2Si_2$	60.9	26.93	12.1	0.00
(Al)	99.55	0.13	0.42	0.000
t = 530 °C (10 area)				
$Al_{15}Si_2Cr_4$	60.49	25.86	9.48	4.15
Al_8Fe_2Si	59.85	32.58	7.5	0.00
$Al_9Fe_2Si_2$	61.39	26.93	11.6	0.00
t = 603 °C (11 area)				
$Al_{15}Si_2Cr_4$	60.79	26.18	9.16	3.85
Al_8Fe_2Si	58.49	32.56	8.94	0.00
t = 671 °C (12 area)				
$Al_{13}Fe_4$	59.53	39.17	1.29	0.00
$Al_{15}Si_2Cr_4$	61.34	25.78	8.62	4.24
Al_8Fe_2Si	57.66	32.55	9.77	0.00
t = 665 °C (13 area)				
$Al_{13}Fe_4$	59.36	39.18	1.45	0.00
$Al_{15}Si_2Cr_4$	61.12	25.5	8.86	4.50
Al_8Fe_2Si	57.48	32.55	9.96	0.00
AlFeSi	52.38	33.91	13.69	0.00
t = 646 °C (14 area)				
$Al_{13}Fe_4$	58.6	39.27	2.11	0.00
$Al_{15}Si_2Cr_4$	60.72	22.61	9.41	7.24
AlFeSi	50.73	33.89	15.37	0.00

A slightly different phase transformation pathway is observed when chromium is introduced by reducing the amount of iron.

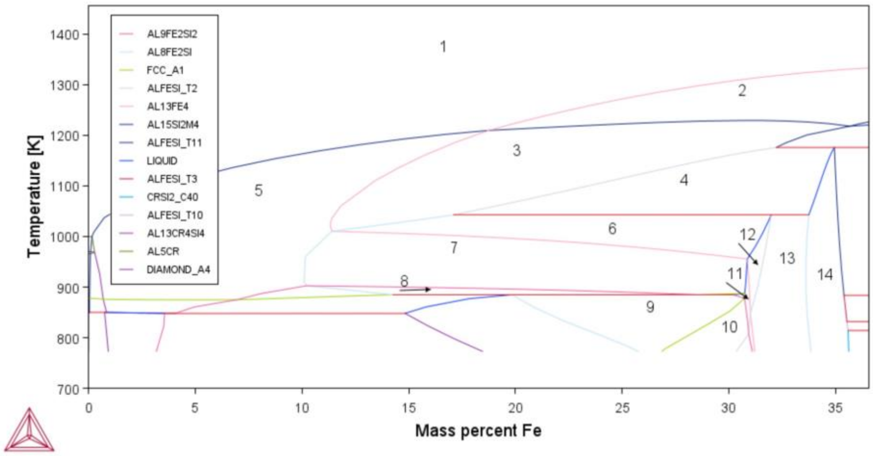

Figure 2 - Polythermal section of the Al-30Fe-9Si-1Cr system with variable aluminum and iron content, with constant silicon and chromium content

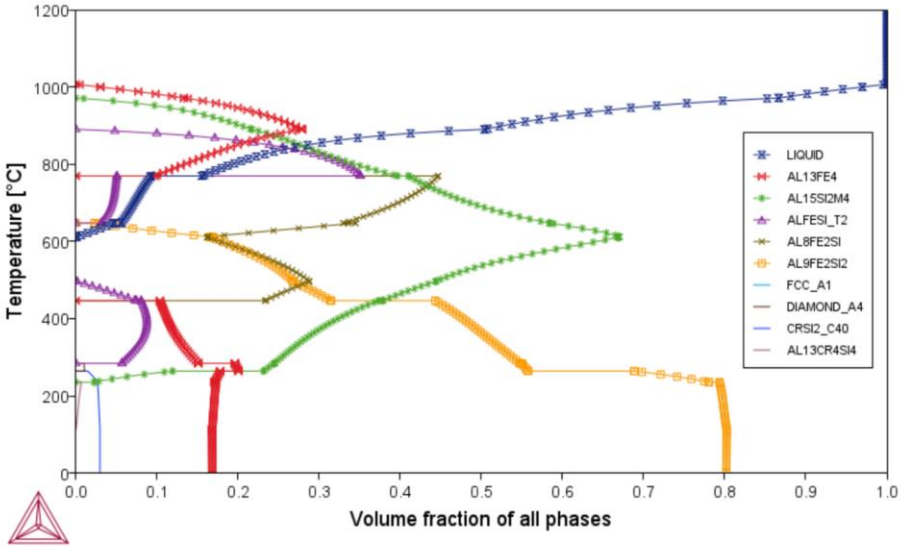

Figure 3 - Volume fraction of all phases depending on temperature in the Al-28Fe-10Si-2Cr alloy

To provide a more detailed analysis of this alloying approach, a polythermal section was constructed (Figure 3), highlighting three regions most favorable for the formation of the primary strengthening phases.

In the first region (3% Cr, 27% Fe), below 980 °C, the θ-phase ($Al_{13}Fe_4$) forms via a eutectic reaction. The temperature range of 980–780 °C corresponds to the stability region of the primary θ-phase. As the temperature further decreases, this phase completely dissolves, accompanied by the formation of the α-phase (Al_8Fe_2Si) in the 770–680 °C range. A subsequent solid-state transformation leads to the re-precipitation of the θ-phase (Region 22) down to room temperature.

At high temperatures, based on the characteristic transformation path, the first phases to precipitate from the melt are hexagonal α (α_h) and cubic α (α_c). Later, αh is fully replaced by the cubic α-phase, stabilized by the chromium addition. Subsequently, the hexagonal α-phase reappears and coexists with the cubic α-phase. The hexagonal α-phase is a high-temperature phase with a narrower stability range (up to 450 °C) compared to its cubic counterpart (stable up to ~240 °C).

In the second region (15% Cr, 15% Fe), the most notable phase formation zones are Regions 2, 8, 24, and 37. In Region 2, a eutectic reaction results in the formation of $CrSi_2$ and α-Cr from the aluminum melt. This transformation concludes in Region 8, where both phases coexist. Chromium disilicide ($CrSi_2$) is an intermetallic compound with a hexagonal structure consisting of alternating layers of chromium and silicon atoms, which defines its mechanical behavior [28]. It exhibits high hardness and brittleness – typical for intermetallics – as well as wear and scratch resistance.

The α_c phase is a hard and brittle intermetallic constituent, which can either enhance or impair the properties of aluminum alloys depending on its morphology and distribution. It is a cubic modification of the α-phase, formed by partially substituting iron atoms with chromium. When uniformly distributed, α_c can inhibit grain growth and stabilize the microstructure. In heat-resistant aluminum alloys, it improves thermal stability. However, in wrought and cast aluminum alloys, this phase can have several detrimental effects, such as increased cracking tendency at elevated temperatures and the creation of internal stress concentrators, reducing ductility and fatigue strength. To minimize these effects, careful control of chromium and silicon content is required, and the use of modifying elements such as Zr, Ti, or Sc may be beneficial for microstructural control.

Region 24 is characterized by the presence of the θ-phase ($Al_{13}Fe_4$), α_c, and the τ_{1Cr} phase within the temperature range of 420–275 °C. This is followed by the formation of the β-phase through a eutectoid transformation (Region 37).

The intermetallic τ_{1Cr} phase ($Al_{13}Cr_4Si_4$ or $Al_{13}Cr_2$) reduces the alloy's tendency to crack and contributes to microstructural stabilization. In this case, chromium acts as a grain growth inhibitor, promoting the formation of a fine-grained, homogeneous structure, which improves the mechanical performance of the alloy. In systems with excess chromium and reduced iron content, conditions are created that favor the formation of this phase instead of the iron-containing θ-phase.

The β-phase ($Al_9Fe_2Si_2$) is one of the most commonly encountered intermetallic compounds in the Al–Si–Fe system. In conventional alloys, it is generally considered undesirable, as it significantly reduces mechanical properties [29]. It commonly forms at grain boundaries as long, needle-like precipitates, sharply decreasing ductility and impact toughness. In intermetallic-rich compositions, the β-phase may also appear as coarse dendrites or flake-like compact particles, typically located along the previously formed θ-phase boundaries.

The third region (27% Cr, 3% Fe) is characterized by a high chromium content, leading to the formation of the Al_4Cr phase, which appears in the structure as a granulated, rounded morphology. Overall, Al_4Cr is considered a favorable phase, as it improves high-temperature strength without significantly compromising corrosion resistance or impact toughness [30].

To quantitatively assess the phase constituents, temperature-dependent volume fraction curves were constructed for all phases along the characteristic transformation paths considered.

As shown in Figure 3, the primary θ-phase ($Al_{13}Fe_4$) crystallizes first at approximately 1000 °C, then dissolves and reprecipitates at around 448 °C. At room temperature, the volume fraction of this phase accounts for approximately 18% of the total alloy volume.

The volume fraction of the α-phase ($Al_{15}(Fe, Cr)_3Si_2$) reaches approximately 68% at 600 °C and is formed over a relatively wide temperature range. The β-phase ($Al_9Fe_2Si_2$) begins to form at 648 °C and continues to exist down to room temperature, comprising about 80% of the total alloy volume in this temperature range.

The α-phase (Al_8Fe_2Si) forms within a relatively narrow and discrete temperature range of 800–445 °C, with a volume fraction of approximately 45%.

Subsequently, a temperature-dependent phase volume fraction diagram was constructed for the Al–27Fe–10Si–3Cr alloy system (Figure 4).

Even a slight increase in chromium content by 1% leads to a significant change in the phase composition. In this case, the α-phase (Al_8Fe_2Si) exhibits a very limited solubility range, constituting only about 18% of the total alloy volume. The volume fraction of the cubic α-phase ($Al_{15}(Fe,Cr)_3Si_2$) reaches 89% at 610 °C, while the amount of β-phase ($Al_9Fe_2Si_2$) decreases to 77% at room temperature. The increase in the cubic α-phase fraction is compensated by the hexagonal α_h phase.

With an increase in chromium content up to 15% (Figure 5), the cubic modification completely replaces the α-phase (Al_8Fe_2Si), with its volume fraction reaching 98% in the temperature range of 980–430 °C. Below 220 °C, a gradual transformation into the β-phase begins, accompanied by the precipitation of θ and $Al_{13}Cr_4Si_4$ phases. Notably, the αCr phase persists down to room temperature.

At the same time, the near-complete substitution of iron with chromium does not promote an increase in the volume fraction of the cubic α-phase ($Al_{15}(Fe, Cr)_3Si_2$) (Figure 6).

On the contrary, the τ_1-Cr phase ($Al_{13}Cr_4Si_4$) begins to dominate in terms of volume fraction, while the hexagonal α-phase is also not formed. It should be noted that in the Al–15Fe–10Si–15Cr composition, increasing the silicon content leads to a reduction in the ($Al_{15}(Fe, Cr)_3Si_2$) phase and the precipitation of free (unbound) silicon.

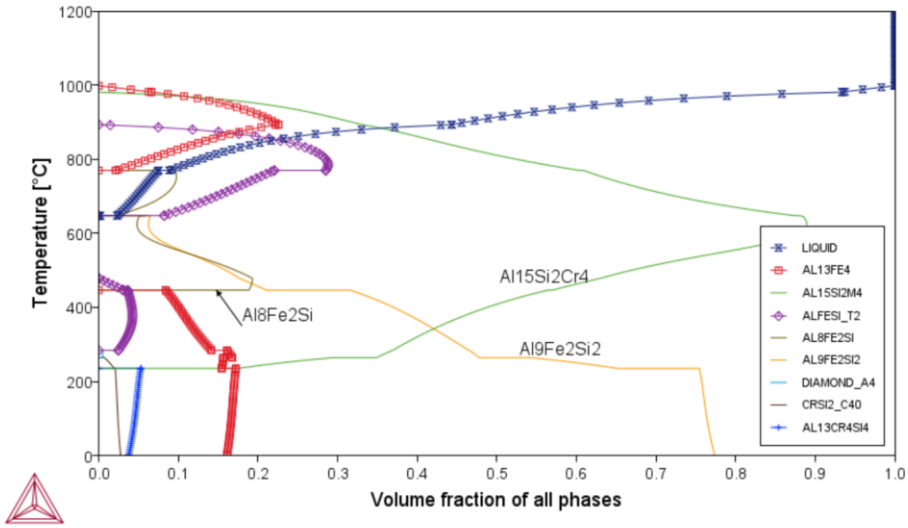

Figure 4 - Volume fraction of all phases depending on temperature in the Al-27Fe-10Si-3Cr alloy

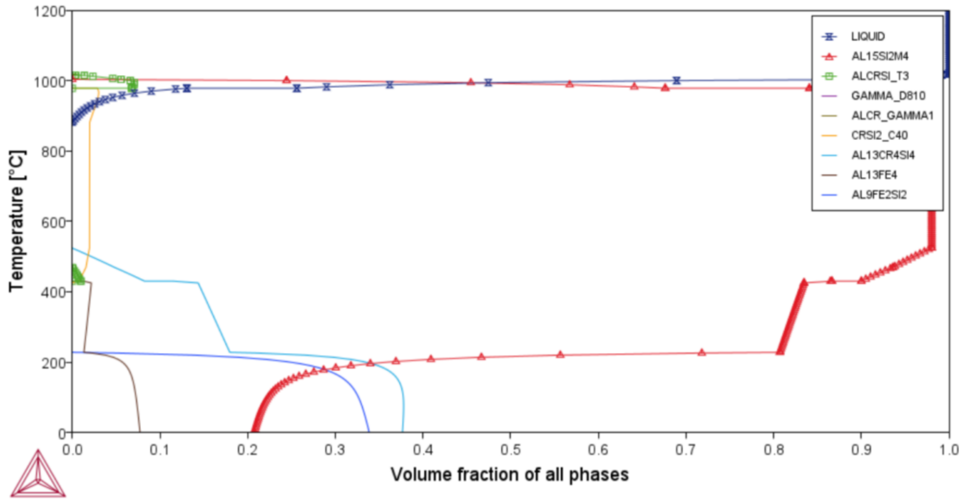

Figure 5 - Volume fraction of all phases depending on temperature in the Al-15Fe-10Si-15Cr alloy

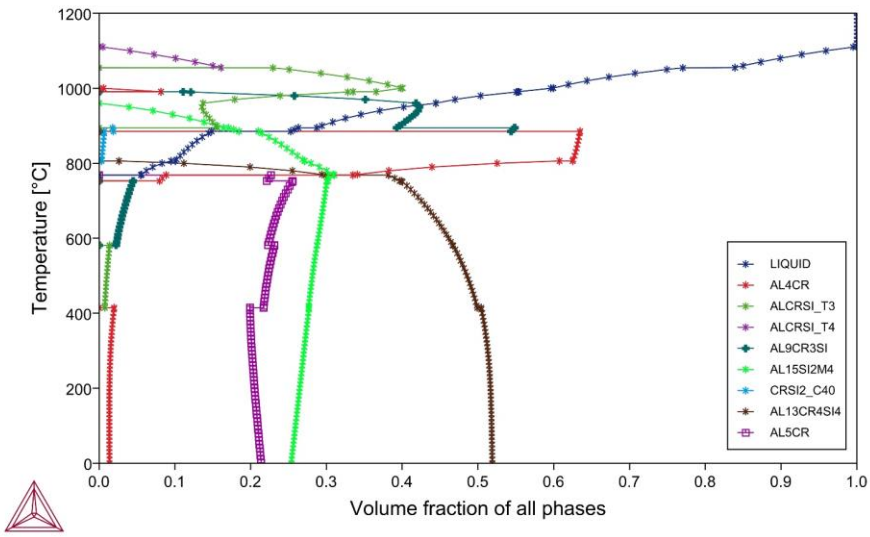

Figure 6 - Volume fraction of all phases depending on temperature in the Al-3Fe-10Si-27Cr alloy

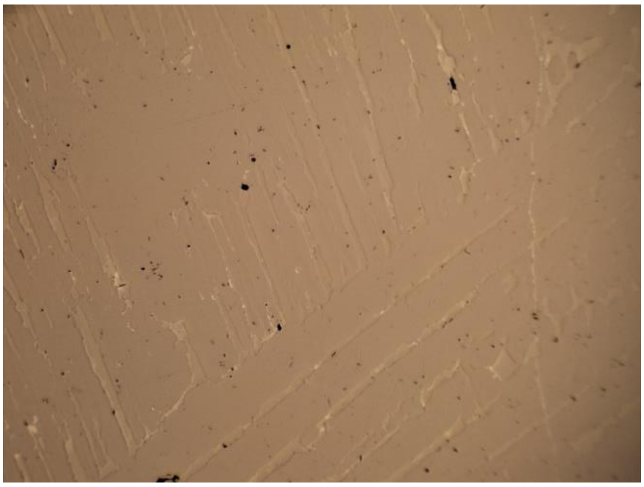

Figure 7 - Microstructure of the Al-Fe-Cr-Si alloy after synthesis, x200

Thus, it has been established that the addition of 2–3% chromium promotes an increase in the fraction of the high-temperature cubic modification of the α-phase, while simultaneously suppressing the growth of the binary θ-phase.

In the Al–15Fe–10Si–3Cr composition, within the temperature range of 980–430 °C, the alloy consists of up to 98% cubic α-phase (αc), with the θ-phase formation significantly suppressed. From our perspective, this phase composition is the most favorable for an intermetallic aluminum alloy.

To validate the obtained modeling results, an additional study was conducted by introducing 3% chromium into the base composition. Figure 7 shows the microstructure of the alloy after chromium addition. As predicted by the modeling results, chromium does not form independent inclusions at room temperature; however, it contributes to the stabilization of the microstructure. After synthesis, the microstructure is predominantly composed of β-phase dendrites, a small fraction of θ-phase distributed between the β-phase dendrites, and a minor amount of chromium-containing phases. The intermetallic compounds exhibit no segregation or cracking.

The primary effect of chromium alloying is manifested in improved stability at elevated temperatures and enhanced plasticity due to the formation of the cubic αc phase.

This study examined the effect of chromium on the properties of aluminum alloys. As an alloying element, chromium plays a crucial role: it enhances structural stability, reduces the risk of defect formation, and improves the mechanical performance of aluminum-based components. Its application may expand the use of aluminum alloys in high-tech industries such as electrical engineering, nuclear power, and aerospace engineering.

Conclusions

A fundamental investigation of the Al–Fe–Si alloy system was conducted with the aim of optimizing its composition. It was found that the use of the base configuration leads to the formation of undesirable morphologies of intermetallic phases. Chromium alloying significantly alters the phase composition, reduces the content of the detrimental θ-phase ($Al_{13}Fe_4$), and promotes the formation of more stable strengthening phases and Cr-containing intermetallics. The introduction of as little as 2% chromium yields notable changes. The obtained results confirm the potential of alloying as an effective approach for developing intermetallic aluminum alloys with tailored properties. This opens new opportunities for advancing the aluminum industry in Kazakhstan and enhancing the global competitiveness of its products. These results hold practical value for the development of new composite materials and for interpreting the microstructure of industrial aluminum alloys.

Conflict of interest. On behalf of all authors, the corresponding author declares that there is no conflict of interest.

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Al-Fe-Si жүйесінің металаралық алюминий қорытпаларының фазалық түзілуіне және микроқұрылымына хромның әсері

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ТҮЙІНДЕМЕ
Мақалада хром қорытпасымен Al-Fe-Si жүйесінің композиттік алюминий қорытпаларын синтездеу үшін аддитивті технологияларды қолдануға баса назар аудара отырып, Қазақстандағы алюминий өнеркәсібінің даму перспективалары қарастырылады. Балқитын электродпен қаптау әдісімен синтезделген қорытпалардың фазалық құрамына кешенді металлографиялық және термодинамикалық талдау жүргізілді. Thermo-Calc бағдарламалық құралын пайдалану политермиялық қималарды салуға және легірлеуші элементтер концентрациясының металаралық фазалардың, соның ішінде Al13Fe4 (θ-фаза) және Al8Fe2Si түзілуіне әсерін анықтауға мүмкіндік берді. Хроммен оңтайлы леглрлеу шарттары негізделді, бұл ұсақ түйіршікті құрылымның пайда болуына, фазалық құрамның тұрақтануына және ірі бастапқы дендриттердің жойылуына байланысты сынғыштықтың төмендеуін және механикалық қасиеттердің жоғарылауын қамтамасыз етеді. Алынған нәтижелер хром қорытпаларының қажетті қасиеттері бар интерметалдық алюминий қорытпаларын әзірлеудегі тиімді тәсіл ретіндегі әлеуетін растайды. Зерттеу нәтижелері жақсартылған өнімділік сипаттамалары бар алюминий қорытпаларын алу технологияларын әзірлеуге ықпал етеді және өнеркәсіпте аддитивті әдістерді қолдану мүмкіндіктерін кеңейтеді.

Түйін сөздер: Al-Fe-Si, интерметалдық фазалар, модельдеу, фазалық түрлендіру диаграммасы, микроқұрылым.

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Влияние хрома на фазообразование и микроструктуру интерметаллидных алюминиевых сплавов системы Al-Fe-Si

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АННОТАЦИЯ
В статье рассмотрены перспективы развития алюминиевой промышленности Казахстана с акцентом на применение аддитивных технологий для синтеза композиционных алюминиевых сплавов системы Al-Fe-Si с легированием хромом. Проведен комплексный металлографический и термодинамический анализ фазового состава сплавов, синтезированных методом наплавки плавящимся электродом. Использование программного обеспечения Thermo-Calc позволило построить политермические разрезы и определить влияние концентрации легирующих элементов на формирование интерметаллических фаз, включая Al13Fe4 (θ-фазу) и Al8Fe2Si. Обоснованы условия оптимального легирования хромом, обеспечивающие снижение хрупкости и повышение механических свойств за счет формирования мелкозернистой структуры, стабилизации фазового состава и устранение крупных первичных дендритов. Полученные результаты подтверждают потенциал легирования хромом как эффективного подхода в разработке интерметаллидных алюминиевых сплавов с заданными свойствами. Результаты исследования способствуют развитию технологий получения алюминиевых сплавов с улучшенными эксплуатационными характеристиками и расширяют возможности применения аддитивных методов в промышленности.

Ключевые слова: Al-Fe-Si, интерметаллидные фазы, моделирование, диаграмма фазовой трансформации, микроструктура.

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